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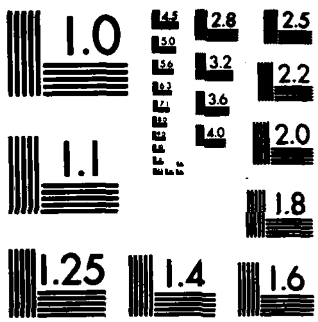

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Thermal and metabolic responses were examined during exposures in stirred water at approximately 20, 26 and 33°C while performing 45 min of either arm (A), leg (L), or combined arm and leg (AL) exercise. Eight males immersed to the neck completed a low exercise intensity for A exercise and both a low and high exercise intensity for L and AL exercise. During low intensity exercise, final metabolic rate (M) for A, L, and AL exercise was not different ($p>0.05$) between exercise type for each water temperature (T_w). In contrast, final rectal temperatures (T_{re}) for A and AL exercise were significantly lower than

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L values for each T_w during low intensity exercise. These findings were supported by both mean weighted skin temperature ($\bar{T}_{sk}$) and final mean weighted heat flow (H_c) values which were greater during A than L for each T_w. During high intensity exercise, final T_{re} values were lower ($p<0.05$) during AL compared with L exercise across all T_w. Final $\bar{T}_{sk}$ and H_c values were not different between each type of exercise although $\dot{M}$ was significantly lower during L exercise in 20°C water. These data suggest a greater conductive and convective heat loss during exercise utilizing the arms when compared with leg only exercise.

THERMAL RESPONSES DURING ARM, LEG AND COMBINED ARM AND LEG EXERCISE IN WATER AT 20, 26 AND 33°C

Michael M. Toner, Michael N. Sawka and Kent B. Pandolf

US Army Research Institute of Environmental Medicine

Natick, MA 01760

Running Title: Thermal Responses During Exercise in Water

Address: Dr. Michael M. Toner
Laboratory of Applied Physiology
Department of Health and Physical Education
Queens College
Flushing, N.Y. 11367

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Abstract

Thermal and metabolic responses were examined during exposures in stirred water at approximately 20, 26 and 33°C while performing 45 min of either arm (A), leg (L), or combined arm and leg (AL) exercise. Eight males immersed to the neck completed a low exercise intensity for A exercise and both a low and high exercise intensity for L and AL exercise. During low intensity exercise, final metabolic rate (M) for A, L, and AL exercise was not different ($p > 0.05$) between exercise type for each water temperature (T_w). In contrast, final rectal temperatures (T_{re}) for A and AL exercise were significantly lower than L values for each T_w during low intensity exercise. These findings were supported by both mean weighted skin temperature ($\bar{T}_{sk}$) and final mean weighted heat flow (H_c) values which were greater during A than L for each T_w. During high intensity exercise, final T_{re} values were lower ($p < 0.05$) during AL compared with L exercise across all T_w. Final $\bar{T}_{sk}$ and H_c values were not different between each type of exercise although M was significantly lower during L exercise in 20°C water. These data suggest a greater conductive and convective heat loss during exercise utilizing the arms when compared with leg only exercise.

arm exercise; leg exercise; combined arm and leg exercise; water immersion; temperature regulation; metabolic rate; rectal temperature; skin temperature; heat flow

INTRODUCTION

Water has been reported to increase the convective heat transfer coefficient about 200 times that reported for still air (10). Previous investigations have concluded that the primary physiological factors influencing heat loss during exercise in cool water are the insulation provided by adipose tissue (9,10,11,16), the intensity of exercise (6,10) and the vasomotor adjustments (10). These immersion studies, however, have only employed swimming or combined arm and leg exercise as the exercise mode. The use of swimming or combined arm and leg exercise maximizes the interface area between the contracting musculature and the water medium. If a given amount of metabolic heat is dissipated over a smaller interface area with cool water (i.e., leg exercise only), a relatively smaller absolute heat flux would be predicted. Another factor that may be important for heat loss in cool water is the surface area to mass ratio ($A_D \cdot wt^{-1}$) of the limbs performing the exercise. Cool water immersion exercise performed with limbs of relatively small (leg) and relatively large (arm) $A_D \cdot wt^{-1}$ ratios would be expected to have different heat exchanges. For a given rate of metabolism, the smaller the $A_D \cdot wt^{-1}$ ratio the smaller the expected absolute heat flux to cool water. Thus, different exercise modes which alter the interface areas of the contracting skeletal muscle mass and also change the $A_D \cdot wt^{-1}$ ratios of the performing limbs could influence thermoregulatory responses during water-immersion exercise.

To our knowledge previous research has not systematically varied exercise type to study the thermoregulatory responses to water-immersion exercise. The present investigation studied the effects of arm, leg and combined arm-leg exercise on selected thermoregulatory responses to exercise in water. These experiments were conducted when immersed in water of 20, 26 and 33°C.

METHODS

Subjects. Eight healthy males volunteered to participate in this study. Prior to all testing, each subject underwent a physical examination and was informed of the purpose of the study and the nature of the risks associated with the testing procedures. Each subject gave his written informed consent.

Anthropometric Evaluation. Body composition was assessed by a hydrostatic weighing technique described by Goldman and Buskirk (7). The percentage of total body fat was computed from body density values by the formula derived by Siri (15), where % Body Fat = 495/density - 450. The physical characteristics of the subjects are presented in Table 1.

Protocol. The subjects initially completed a series of three non-experimental sessions. During these sessions the subjects were familiarized with the test procedures and completed submaximal and maximal effort tests for the three types of exercise in air. Exercise was peformed on an arm-leg ergometer that we have previously described (18). The three types of exercise were only arms (A), only legs (L) and combined arm and leg (AL) exercise.

Based upon information obtained during the non-experimental sessions, the following discontinuous peak $\dot{V}O_2$ tests were developed. For A exercise, each subject completed a 5 min warm-up then performed exercise at a power output (PO) which elicited a heart rate of 85% of age predicted maximum for arm exercise (220-age-10, $b \cdot min^{-1}$) (13). Each work bout was 3 min in duration and PO was increased by 20 W following a 10-min rest period. During $\dot{V}O_2$ peak tests for L and AL, following a 5-min warmup subjects performed exercise at a PO which elicited 80% of age predicted maximal heart rate (220-age, $b \cdot min^{-1}$). The incremental increase in exercise PO during L exercise was 30 W. During AL exercise, the distribution of the arm exercise intensity to the total intensity was between 20 and 40%; the incremental increase was 10 W for the

arms and 20 W for the legs. During all peak $\dot{V}O_2$ tests, subjects were verbally encouraged to complete each exercise intensity and the test was discontinued when the 40 rpm pedal rate could not be maintained. All peak $\dot{V}O_2$ values were verified during a second test session.

Based on the peak $\dot{V}O_2$ values, a low and a high intensity exercise PO was chosen for the water experiments. Exercise intensities for A, L and AL exercises were chosen to match the metabolic rates for all three exercise types. In addition, these two selected intensities approximated 40 and 60% of the peak $\dot{V}O_2$ for AL exercise. Both metabolic intensities were performed with L and AL, whereas A exercise was performed at only the lower intensity during immersion.

The leg ergometer was modified for use in water by a method previously described by this laboratory (14). The graded exercise intensity on an immersed Monark cycle ergometer was obtained by attaching fins to the flywheel. In this fashion, the pedal rate was maintained while exercise intensity was increased by increasing the numbers of fins placed on the flywheel. The rate of 40 rpm was chosen to enable smaller gradations in exercise intensity between fin numbers. In addition, a half fin (186 mm) was used to further reduce the gradations in exercise intensity. The crank of the arm ergometer was immersed while the flywheel remained in air and was protected by splash guards.

All water experiments were carried out in a 36,000 liter pool having precise temperature control ($\pm 0.5^{\circ}C$). Water was continuously circulated by compressed air, bubbled from the bottom of the pool. All exercise procedures were performed with the subject immersed up to the neck in water at 20, 26 and $33^{\circ}C$ for a duration of 45 min. For each subject, the presentation of exercise type and exercise intensity was randomly ordered. Subjects dressed in bathing suits arrived at the laboratory one h prior to immersion to complete harnessing and a controlled-rest period in air. Subjects were required to initiate pedaling immediately after entering the water.

Physiological Measures. Oxygen uptake ($\dot{V}O_2$) was determined by open circuit spirometry where expired air was collected in Douglas bags and analyzed for oxygen (Applied Electrochemistry, S-3 A) and carbon dioxide (Beckman, LB-2) concentrations. These analyzers were calibrated prior to each sample analysis with gases previously verified by the micro-Scholander technique. Expired air volumes were measured by a 120-liter Tissot spirometer and corrected to standard conditions. Metabolic rate (M) was calculated from oxygen uptake and carbon dioxide production using the Weir formula (19).

Rectal temperature (T_{re}) was measured by the insertion of a thermistor approximately 10 cm into the rectum and held in place by an elastic strap tied to the front and back of a waist belt. Mean weighted skin temperature ($\bar{T}_{sk}$) of the immersed part of the body was measured on the left side by a nine-point thermocouple harness with one layer of tape covering each thermocouple. Area weighting was as follows: $\bar{T}_{sk} = 0.06\ T_{foot} + 0.17\ T_{calf} + 0.14\ T_{medial\ thigh} + 0.14\ T_{lateral\ thigh} + 0.14\ T_{chest} + 0.07\ T_{tricep} + 0.07\ T_{forearm} + 0.14\ T_{back} + 0.07\ T_{hand}$. Heat flow discs (RdF Corp., New Hampshire) were applied to the back, forearm, triceps, calf, thigh and forehead with one layer of double-backed adhesive tape. Temperature and heat flow measurements were recorded by a Hewlett-Packard 9825B calculator following processing through a Hewlett Packard 3456A Digital Voltmeter (± 0.1 µV accuracy). The conductive heat transfer coefficient (h_k) was computed as follows: h_k = heat flow/($T_{re} - \bar{T}_{sk}$).

Statistical Analysis. Metabolic and thermal responses were evaluated by a two factor, repeated measures design for analysis of variance. The Tukey multiple-range test and the procedure outlined by Cicchetti (5) were used when the analysis of variance yielded a significant ($p < 0.05$) difference between means.

RESULTS

Table 2 presents the average peak $\dot{V}O_2$ values and the related cardiorespiratory responses during A, L and AL exercise. The peak $\dot{V}O_2$ values during A and L exercises, relative to the peak $\dot{V}O_2$ during AL exercise, were 72 and 94%, respectively. Pulmonary ventilation ($\dot{V}_E$) and heart rate (HR) responses maintained similar proportions relative to the peak $\dot{V}O_2$ values between exercise type. Also, respiratory exchange ratios were similar between exercise types.

All subjects completed each specified type of exercise at both the high and low intensity in each water temperature (T_w). In 20°C water, M increased slightly ($p < 0.05$) with time during low intensity exercise for A (Δ M, 56 W) and AL exercise (Δ M, 102 W). However, M was not significantly different ($p > 0.05$) across time during L exercise (Δ M, 41 W). During high intensity exercise, M remained constant throughout the exposure period in the coldest water. In general, M did not change across time in either 26 or 33°C during both low and high intensity exercise within each exercise type.

Final M values during A, L and AL exercise are illustrated in Figure 1. There were no differences ($p > 0.05$) in M between exercise types during the low intensity in each T_w. During high intensity exercise, M differed ($p < 0.05$) between L and AL exercise only in 20°C water. During low intensity exercise, M was significantly higher in 20 and 26°C compared with 33°C water during A exercise, whereas M was higher in 20°C compared with 26 and 33°C water during L and AL exercise. During high intensity exercise, there were no differences between exercise types across T_w.

In 20°C water, T_{re} declined ($p < 0.05$) steadily during low intensity exercise for A (Δ T_{re}, -0.95°C), L (Δ T_{re}, -0.57°C) and AL exercise (Δ T_{re}, -0.96°C), whereas during high intensity exercise T_{re} remained constant during L exercise (Δ T_{re}, -0.10°C) and decreased ($p < 0.05$) during AL exercise (Δ T_{re}, -0.46°C). In

26°C, T_{re} declined slightly during low intensity A (ΔT_{re}, -0.28°C) and AL exercise (ΔT_{re}-0.49°C) while L values remained essentially unchanged (ΔT_{re}, 0.12) throughout the immersion period. During high intensity exercise in 26°C, T_{re} steadily increased ($p < 0.05$) in both L (ΔT_{re}, 0.46°C) and AL exercise (ΔT_{re}, 0.21°C). In 33°C during low intensity exercise, T_{re} was higher ($p < 0.05$) after 45 min of exercise (ΔT_{re}, 0.30°C), whereas A (ΔT_{re}, 0.09°C) and AL (ΔT_{re}, 0.08°C) were not different across time. During high intensity exercise in 33°C, T_{re} increased significantly ($p < 0.05$) over time in both L (ΔT_{re}, 0.40°C) and AL (ΔT_{re}, 0.45°C).

Final T_{re} responses are shown in Figure 2. Differences in final T_{re} values were noted between exercise types during low intensity exercise. The final T_{re} responses for A and AL exercise were statistically lower than L values across all T_w. This overall difference between L and both A and AL was approximately 0.3°C (range, 0.0-0.4°C). During high intensity exercise, T_{re} values were lower ($p < 0.05$) during AL exercise compared with L across all T_w. The overall difference between L and AL across T_w was 0.2°C (range, 0.08 -0.34°C). The T_{re} values were also lower ($p < 0.05$) during low and high intensity exercise in 20°C as compared with 26 and 33°C water.

During low intensity exercise, final $\bar{T}_{sk}$ were significantly higher during A compared with L exercise in 20°C (A = 21.0; L = 20.7°C), 26°C(A = 26.6; L = 26.4°C) and 33°C water (A = 33.3; L = 33.0°C), whereas there were no differences between AL and either A or L exercise in 20°C (AL = 20.9°C), 26°C (AL = 26.5°C) and 33°C water (AL = 33.0°C). During high intensity exercise, final $\bar{T}_{sk}$ were 20.9, 26.6, and 33.2°C during L exercise as compared with 20.9, 26.2 and 33.1°C during AL exercise in water at 20, 26 and 33°C, respectively. These final $\bar{T}_{sk}$ values were not different ($p > 0.05$) across exercise type while significant differences were noted between each T_w.

Figure 3 presents the final mean weighted heat flow (H_c) values from the immersed part of the body. During low intensity exercise, H_c values were significantly higher during A as compared with L exercise across all T_w. However, there were no differences for AL as compared with A and L exercise. Final H_c values were higher with decreasing T_w. During the high intensity exercise, there were no differences ($p > 0.05$) in H_c between AL and L exercise across all T_w. However, final H_c values were significantly lower ($p < 0.05$) during both AL and L exercise in 33°C as compared with 26 and 20°C.

DISCUSSION

To our knowledge, there is no study which has systematically varied the type of exercise to gain further insight into the physiological or biophysical factors which contribute to heat transfer during water immersion. Thus, the present investigation compared thermal responses during exercise performed at similar metabolic rates by the arms, legs and combined arms and legs. Our data demonstrated that the final rectal temperature values are significantly lower when exercise is performed by the arms and combined arms and legs when compared with the legs alone. This observation could be the result of increased conductive and convective heat transfer for arm exercise during water immersion.

We can postulate several mechanisms by which arm exercise would have greater conductive heat transfer than leg exercise. The increased heat transfer from the core to the skin could be the result of less subcutaneous fat distributed on the arms, as compared with the legs. Therefore, metabolic heat released in the arms during exercise would have less insulative resistance than similar intensity exercise performed by the legs. Another possible explanation for greater heat conduction could be related to perfusion of the active skeletal

musculature. The increase in cardiac output during exercise (when a heat stress is not present) is primarily directed to the active skeletal muscle. The cardiac output/oxygen uptake relationship has been shown to be similar for A and L exercise (2,17). Since the A exercise employed a smaller skeletal muscle mass than L exercise, the blood flow per unit limb volume would be substantially greater during A than L exercise. Therefore, during A exercise a relatively greater circulatory perfusion of warm blood could substantially increase the potential for convective heat transfer from the core to the skin. In addition, the axial conductive pathway is relatively shorter from the core of the arm to the surface. Thus, a given blood perfusion in the exercising arms has less resistance to heat transfer compared to a similar metabolic intensity for the legs.

Greater conductive and convective heat transfer at the skin-water interface during A exercise may also be attributed to the larger $A_D \cdot wt^{-1}$ ratio and smaller mass of the arms. According to the values for limb volume and surface area described by Burton (4), the $A_D \cdot wt^{-1}$ ratio of the arms is nearly twice that of legs. Theoretically derived equations of forced convection would suggest that the arms, being smaller diameter cylinders than the legs, would have a greater convective coefficient (20). Calculations of convective heat transfer coefficients (h_c) are extremely difficult in water. Boutelier et al. (3) pointed out the large discrepancies in values presented in the literature. In the present investigation, one layer of tape was applied over thermocouples. Several measurements of $\bar{T}_{sk}$ showed little or no difference between skin and water temperature, especially in water at 33°C. Although unsubstantiated from measurements in the present investigation, it is plausible that these differences in rectal temperature response with L exercise can be attributed to greater convection of heat away from the skin during both A and AL exercise.

As shown in the present study, the maintainance of body core temperature during exposure to both 26 and 33°C water can be explained by the h_k values. The average h_k value of all subjects dropped from 32.5 $W \cdot m^{-2} \cdot {}^{o}K^{-1}$ in 33°C down to 21.0 $W \cdot m^{-2} \cdot {}^{o}K^{-1}$ in 26°C water during low intensity exercise. This decrease probably resulted from peripheral vasomotor adjustments. These adjustments enabled the exercising individual to reasonably maintain core temperatures despite variation of 7°C in water temperature. However, little additional vasoconstriction (h_k = 20.0 $W \cdot m^{-2} \cdot {}^{o}K^{-1}$) was achieved when in 20°C water and, therefore, the maintainance of core temperature is not possible by vasoconstriction.

Core temperature can be better maintained in water by increasing the metabolic intensity of exercise. Once near maximum vasomotor adjustments have been achieved, core temperature responses for an individual become the function of peripheral convective heat loss and metabolic heat production. It is reasonable to suggest that the insulation afforded at the skin-water interface is nearly constant across exercise intensities because the forced convection is nearly identical. Higher T_{re} values during the high intensity AL and L exercise compared with low intensity in all T_w indicate that the added heat production contributed to the maintainence of core temperature. Both Äikas et al. (1) and Saltin et al. (12) have shown that muscle temperature is dependent upon exercise intensity and, therefore, would suggest that during the higher intensity exercise, the gradient between limb-core temperature and skin temperature would be larger. In addition, the limb blood flow is also intensity dependent and would also be greater during higher intensity exercise. Despite these potential contributors to heat loss, H_c values were similar and T_{re} values greater during high intensity compared with low intensity exercise. It appears reasonable to suggest that a greater proportion of heat is transferred to the core via circulation during high intensity exercise when compared with low intensity.

The results from this study have possible applications for survival situations. Several investigators (8,9) have pointed out the fall in rectal temperature is greater during exercise than during rest despite higher M values during exercise. In both 15 and 5°C water, Keatinge (9) demonstrated that the fall in rectal temperature during rest was 0.47°C less than during exercise. Hayward (8) substantiated this earlier work and demonstrated 0.37°C less change in rectal temperature during rest as compared with exercise. However, both studies used combined arm and leg exercise as a mode of exercise. The present study suggests that L exercise only performed at high intensity may show similar or higher rectal temperature responses compared with rest. Further experimentation needs to be carried out with L exercise in colder water and these results contrasted with exposures during rest.

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Present address of M.M. Toner: Laboratory of Applied Physiology, Department of Health and Physical Education, Queens College, Flushing, New York 11367

DISCLAIMER

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation.

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on the Use of Volunteers in Research.

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TABLE 1. Physical Characteristics of the Subjects.

	Age (year)	Ht (cm)	Wt (kg)	A_D (m^2)	A_D/m ($dm^2 \cdot kg^{-1}$)	Body Fat %
$\bar{X}$	22.4	171.1	70.9	1.84	2.60	13.4
SD	3.6	5.0	6.2	0.10	0.10	5.7

TABLE 2. Peak $\dot{V}O_2$ Values and Related Cardiorespiratory Responses During Arm, Leg and Combined Arm and Leg Exercise

		$\dot{V}_E$ ($l \cdot min^{-1}$, BTPS)	$\dot{V}O_2$ ($l \cdot min^{-1}$, STPD)	$\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	HR ($b \cdot min^{-1}$)	R	Peak PO (W)
Arm	$\bar{X}$	95.1	2.54	35.5	187	1.20	136
	SD	20.5	0.40	4.6	9	0.10	22
Leg	$\bar{X}$	119.5	3.34	46.5	190	1.27	242
	SD	21.3	0.53	6.5	8	0.06	34
Arm-Leg	$\bar{X}$	123.0	3.56	49.9	192	1.17	274
	SD	10.7	0.47	6.1	8	0.07	4

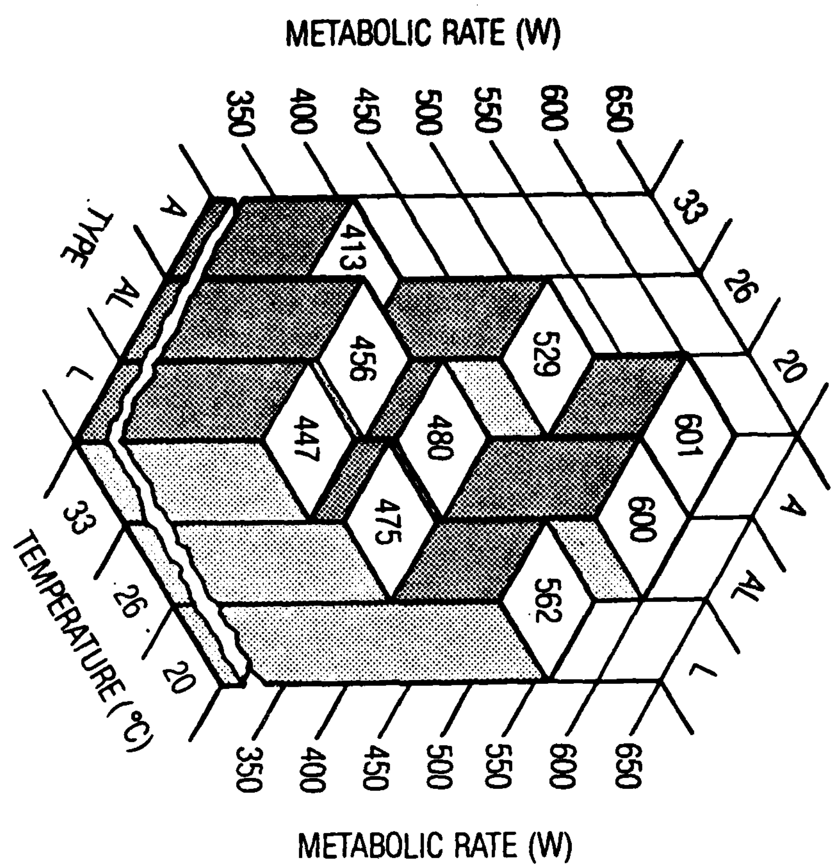
$\dot{V}_E$ is pulmonary ventilation; $\dot{V}O_2$ is O_2 uptake; HR is heart rate; R is respiratory exchange ratio; PO is power output.

FIGURE LEGEND

Figure 1. Final metabolic rates during arm (A), leg (L) and arm-leg (AL) exercise in water at 20, 26 and 33°C. Responses for low intensity exercise are shown to the left and those to high intensity exercise are at the right.

Figure 2. Final rectal temperatures during arm (A), leg (L) and arm-leg (AL) exercise in water at 20, 26 and 33°C. The position for the low and high intensity responses is the same as for Figure 1.

Figure 3. Final mean weighted heat flows during arm (A), leg (L) and arm-leg (AL) exercise in water at 20, 26 and 33°C. The position for the low and high intensity responses is the same as for Figure 1.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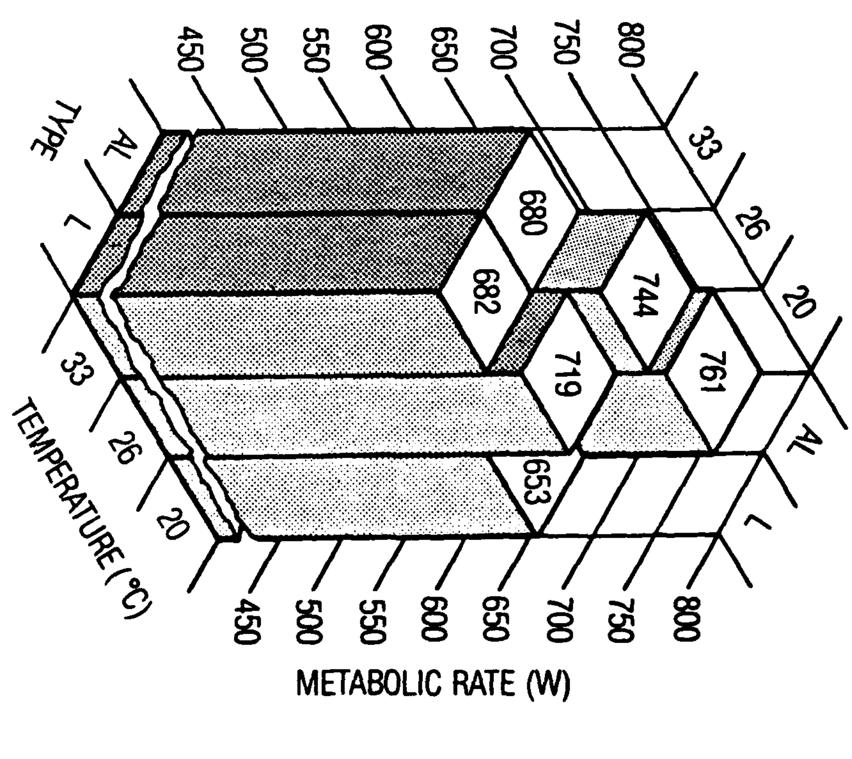
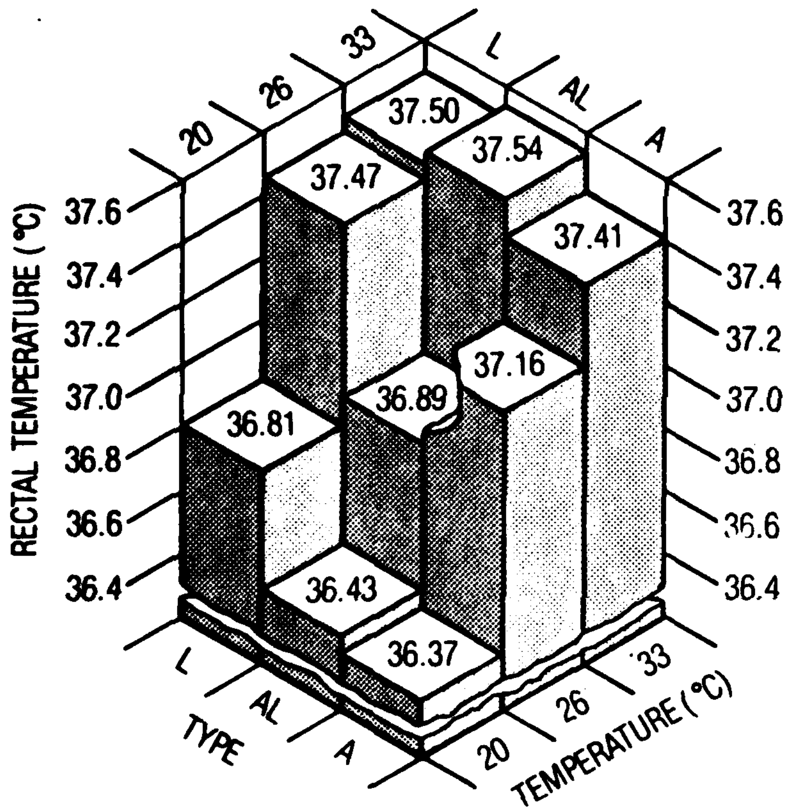
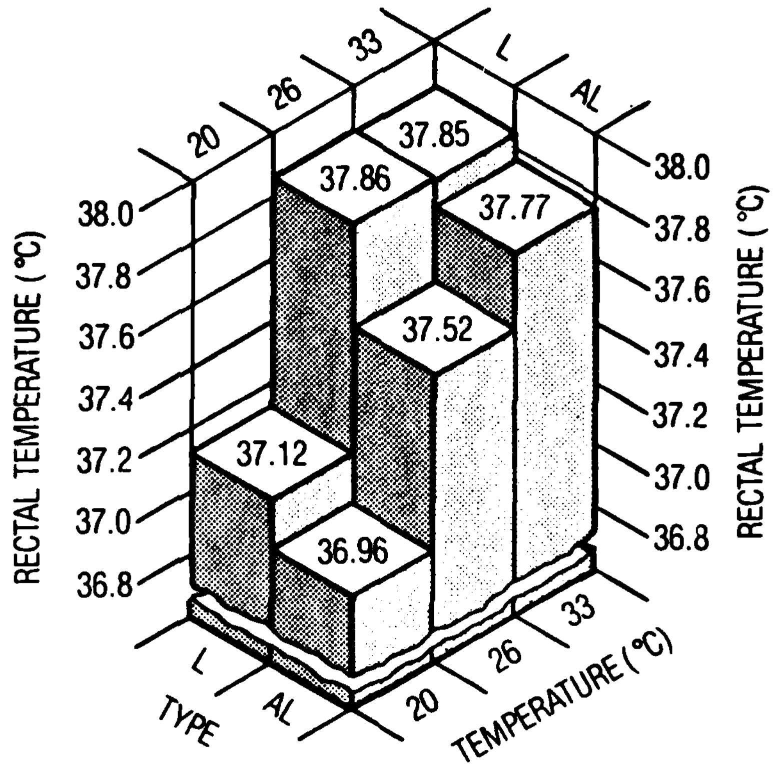
600
562

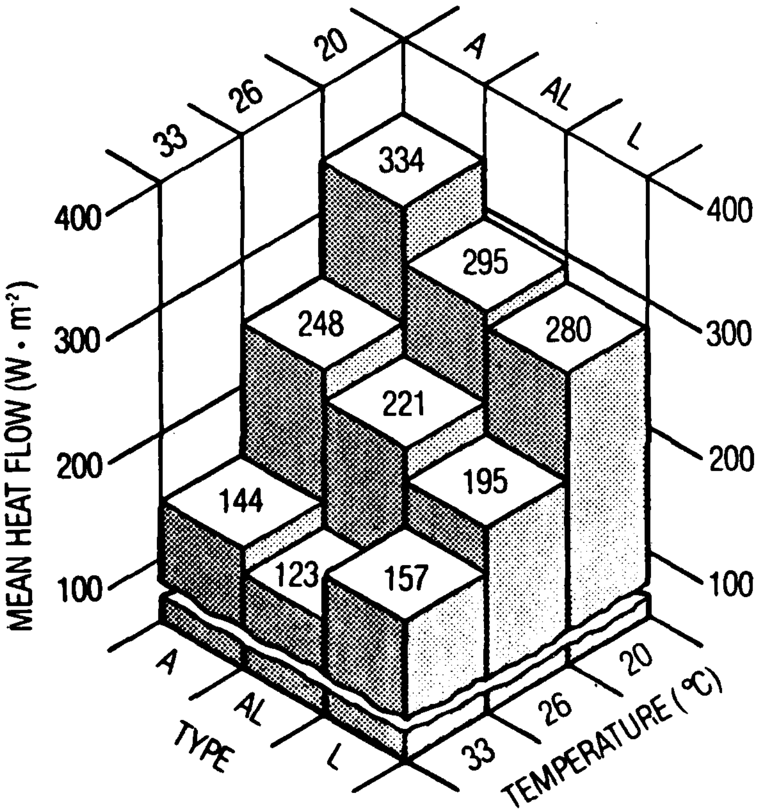

METABOLIC RATE (W)
450
500
550
600
650
700
750
800
TYPE
AL
L
TEMPERATURE (°C)
33
26
20
680
682
744
719
761
653

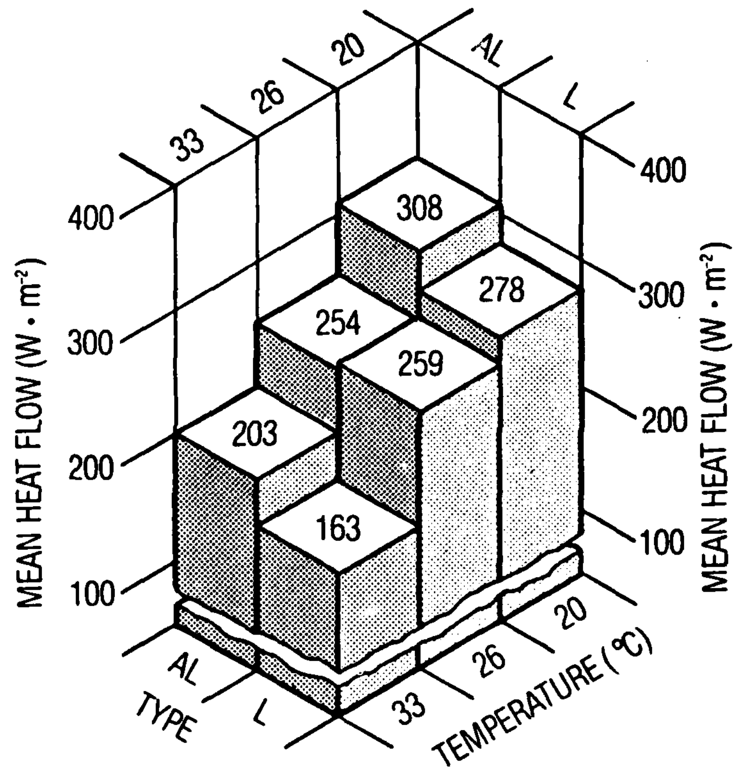


RECTAL TEMPERATURE (°C)
37.6
37.4
37.2
37.0
36.8
36.6
36.4
20
26
33
L
AL
A
37.50
37.54
37.47
37.41
37.16
36.89
36.81
36.43
36.37
TYPE
TEMPERATURE (°C)



RECTAL TEMPERATURE (°C)
38.0
37.8
37.6
37.4
37.2
37.0
36.8
20
26
33
L
AL
37.85
37.86
37.77
37.52
37.12
36.96
TYPE
TEMPERATURE (°C)


MEAN HEAT FLOW (W · m⁻²)
100
200
300
400
33
26
20
A
AL
L
334
295
280
248
221
195
144
123
157
TYPE
TEMPERATURE (°C)


MEAN HEAT FLOW (W · m⁻²)
100
200
300
400
33
26
20
AL
L
308
278
254
259
203
163
TYPE
TEMPERATURE (°C)

END

DATE
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